Executive Summary

In 2004, the U.S. Environmental Protection Agency (EPA) released the *Updated Report on the Incidence and Severity of Sediment Contamination in Surface Waters of the United States: National Sediment Quality Survey*, which identifies areas in all regions of the country where sediment may be contaminated at potentially harmful levels (U.S. EPA 2004a). Contaminated sediment can significantly impair the navigational and recreational uses of rivers and harbors in the U.S. [National Research Council (NRC) 1997 and 2001] and can be a contributing factor in many of the 3,221 fish consumption advisories nationwide (U.S. EPA 2005a). As of 2004, EPA had decided to take action to clean up contaminated sediment at approximately 140 sites, including federal facilities, under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and additional sites under the Resource Conservation and Recovery Act [(RCRA), U.S. EPA 2004a]. The remedies for more than 60 sites are large enough that they are being tracked at the national level. Many other sites are being cleaned up under state authorities, other federal authorities, or as voluntary actions.

This document provides technical and policy guidance for project managers and management teams making remedy decisions for contaminated sediment sites. It is primarily intended for federal and state project managers considering actions under CERCLA, although technical aspects of the guidance are also intended to assist project managers addressing sediment contamination under RCRA. Many aspects of this guidance also will be useful to other governmental organizations and potentially responsible parties (PRPs) that may be conducting a sediment cleanup. Although aspects related to site characterization and risk assessment are addressed, the guidance focuses on considerations regarding feasibility studies and remedy selection for contaminated sediment. The guidance is lengthy, and users may wish to consult sections most applicable to their current need. To help in this process, a short summary of each of the eight chapters is provided below. Sediment cleanup is a complex issue, and as new techniques evolve, EPA will issue new or updated guidance on specific aspects of contaminated sediment assessment and remediation. Links to guidance and additional information about contaminated sediments at Superfund sites are available at http://www.epa.gov/superfund/resources/sediment.

Chapter 1, Introduction, describes the general backdrop for contaminated sediment remediation and reiterates EPA's previously issued Office of Solid Waste and Emergency Response (OSWER) Directive 9285.6-08, *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (U.S. EPA 2002a). Other issues addressed in Chapter 1 include the role of the natural resource trustees, states, Indian tribes, and communities at sediment sites. Where there are natural resource damages associated with sediment sites, coordination between the remedial and trusteeship roles at the federal, state, and tribal levels is especially important. In addition to their role as natural resource trustees, certain state cleanup agencies and certain Indian tribes or nations have an important role as co-regulators and/or affected parties and as sources of essential information. Communities of people who live and work adjacent to water bodies containing contaminated sediment should be given understandable information about the safety of their activities, and be provided significant opportunities for involvement in the EPA's decision-making process for sediment cleanup.

Chapter 2, Remedy Investigation Considerations, introduces investigation issues unique to the sediment environment, including those related to characterizing the site, developing conceptual site models, understanding current and future watershed conditions, controlling sources, and developing cleanup goals. Especially important at sediment sites is the development of an accurate conceptual site model, which identifies contaminant sources, transport mechanisms, exposure pathways, and receptors at various levels of the food chain. Project managers should consider the role of a sediment site in the watershed context, including other potential contaminant sources, key issues within the watershed, and current and reasonably anticipated or desired future uses of the water body and adjacent land. Important parts of site characterization and remedy selection include the identification and, where feasible, control of significant continuing sources of contamination and an accurate understanding of their contribution to site risk and potential for recontamination. It is also generally important that remedial action objectives, remediation goals, and cleanup levels are based on site-specific data and are clearly defined. At most Superfund sites, chemical-specific remediation goals should be developed into final sediment cleanup levels by weighing the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) balancing and modifying criteria.

In addition, Chapter 2 introduces issues relating to sediment mobility and contaminant fate and transport, and modeling at sediment sites. In most aquatic environments, surface sediment and associated contaminants move over time. An important part of the remedial investigation at many sediment sites is a site-specific assessment of whether movement of contaminated sediment (surface and subsurface), or of contaminants alone, is occurring or may occur at scales and rates that will significantly change their contribution to risk. For example, is significant sedimentation of cleaner sediment burying contaminated sediment, and, if so, how quickly, and is erosion likely to re-expose those contaminants in the future? An accurate assessment of sediment mobility and contaminant fate and transport can be one of the most important factors in identifying areas suitable for monitored natural recovery (MNR), in-situ caps, or near-water confined disposal facilities (CDFs). Evaluation of alternatives should include consideration of disruption from man-made (anthropogenic) causes such as propeller scour and natural causes such as floods and ice scour. Generally, this evaluation should include the 100-year flood and other events with a similar probability of occurrence. Project managers should make use of the variety of field and laboratory measurement methods available for evaluating site characteristics. For example, the shear stress necessary to erode sediment or the increase in exposure of biota that might be expected from any contaminants transported to surface water from ground water.

Where appropriate, project managers also should make use of numerical models for predicting future conditions at a site. There is a wide range of models, from simple to complex, which can be applied to contaminated sediment sites. Where numerical models are used, verification, calibration, and validation should be typically preformed to yield a scientifically defensible study. While quantitative uncertainty analyses can be performed for watershed loading and food web models, at the current time they cannot be generally performed for fate and transport models. However, frequently a sensitivity analysis can be used to identify the model parameters that have most impact on model results, so that the project team can ensure that these parameters are well constrained by site data.

Chapter 3, Feasibility Study Considerations, supplements existing EPA guidance by offering sediment-specific guidance about developing alternatives, applying the NCP remedy selection criteria, identifying applicable or relevant and appropriate requirements (ARARs), evaluating effectiveness and permanence, estimating cost, and using institutional controls. Major alternatives include dredging and excavation, in-situ capping, and MNR. Innovative lab and field testing of in-situ treatment in the form of reactive caps or sediment additives are underway and may be useful in the future. Due to the limited number of cleanup methods available for contaminated sediment, generally project managers should evaluate each of the three potential remedy approaches (sediment removal, capping, and MNR) at every sediment site. At large or complex sites, project managers have found that alternatives that combine a variety of approaches are frequently cost effective. Pursuant to CERCLA section 121, all final remedial actions at CERCLA sites must be protective of human health and the environment, and must comply with ARARs unless a waiver is justified. Developing accurate cost estimates is an important part of evaluating sediment alternatives. Project managers should evaluate capital costs, operation and maintenance costs (including long-term monitoring), and net present value. When evaluating alternatives with respect to effectiveness and permanence, it is important to remember that each of the three potential remedy approaches may be capable of reaching acceptable levels of effectiveness and permanence, and that site-specific characteristics should be reviewed during the alternatives evaluation to ensure that the alternative selected will be effective in that environment. Institutional controls are frequently evaluated as part of sediment alternatives to prevent or reduce human exposure to contaminants. Common types of institutional controls at sediment sites include fish consumption advisories, commercial fishing bans, and waterway use restrictions. In some cases, land use restrictions or structure maintenance agreements have also been important elements of an alternative.

Chapter 4, Monitored Natural Recovery, describes the natural processes that should be considered when evaluating MNR as a remedy, and briefly discusses enhanced natural recovery through thin-layer placement of sand or other material. MNR is a remedy that typically uses known, ongoing, naturally occurring processes to contain, destroy, or otherwise reduce the bioavailability or toxicity of contaminants in sediment. An MNR remedy generally includes site-specific cleanup levels and remedial action objectives, and monitoring to assess whether risk is being reduced as expected. Although a “no action” decision may also include monitoring, in this case the monitoring is intended to ensure that an already-acceptable level of risk is maintained (e.g., that deeply buried contaminants are not re-exposed by erosion). Although burial by clean sediment is often the dominant process relied upon for natural recovery, multiple physical, biological, and chemical mechanisms frequently act together to reduce risk. Evaluation of MNR should be usually based on site-specific data, including multiple lines of evidence such as decreasing trends of contaminant levels in fish, in surface water, and in sediment. Project managers should evaluate the long-term stability of the sediment bed and the mobility of contaminants within it. Contingency measures should be included as part of a MNR remedy when there is significant uncertainty that the remedial action objectives will be achieved within the predicted time frame. Generally, MNR should be used either in conjunction with source control or active sediment remediation.

In addition, Chapter 4 discusses the potential advantages and limitations of MNR. In most cases, the two key advantages of MNR are its relatively low implementation cost and its non-invasive nature. While costs associated with site characterization and modeling can be extensive, the costs associated with implementing MNR are primarily associated with monitoring. Because no construction or infrastructure is needed, it is generally much less disruptive to human communities and the ecosystem than active remedies. Two key limitations of MNR may be that it generally leaves contaminants in place without engineered containment and that it can be slow in reducing risks in comparison to active remedies. As with any risk reduction approach that takes a period of time to reach remediation goals, remedies that include MNR frequently rely upon institutional controls, such as fish consumption advisories, to control human exposure during the recovery period. At most sites, some people will disregard advisories despite best efforts to communicate risk, and advisories have no ability to reduce ecological exposures.

Chapter 5, In-Situ Capping, summarizes the major capping technologies and describes the site conditions that are important to understand in evaluating the feasibility and effectiveness of in-situ capping. In-situ capping refers to the placement of a subaqueous covering or cap of clean material over contaminated sediment that remains in place. Caps are generally constructed of clean sediment, sand, or gravel, but can also include geotextiles, liners, or the addition of material, such as organic carbon, to attenuate the flux of contaminants into the overlying water. Depending on the contaminants and sediment conditions present, a cap is generally designed to reduce risk through the following primary functions: 1) physical isolation of the contaminated sediment sufficient to reduce exposure due to direct contact and to reduce the ability of burrowing organisms to move contaminants to the cap surface; 2) stabilization of contaminated sediment and erosion protection of sediment and cap sufficient to reduce resuspension and transport of contaminants into the water column; and 3) chemical isolation of contaminated sediment sufficient to reduce exposure from dissolved contaminants that may be transported into the water column.

In addition, Chapter 5 discusses the potential advantages and limitations of in-situ capping. One advantage of in-situ capping is that it can quickly reduce exposure to contaminants. Also, compared to sediment removal it normally requires both less infrastructure in terms of material handling, dewatering, and disposal and is typically less disruptive to people in local communities. Compared to MNR, the potential for erosion and transport of contaminants is typically much lower. However, contaminated sediment is still left in place in the aquatic environment where contaminants could be exposed or dispersed if the cap is significantly disturbed or if contaminants move through the cap in significant amounts. Another potential limitation to in-situ capping may be that in some situations a preferred habitat may not be provided by the surficial cap materials which may be needed for erosion control.

Chapter 6, Dredging and Excavation, describes dredging technologies (conducted under water) and excavation technologies (typically conducted after water is diverted or drained). The chapter describes some of the key components involved in a sediment dredging or excavation remedy and describes site conditions that may be important when evaluating the feasibility and effectiveness of these remedies. A dredging or excavation alternative should include an evaluation of all phases of the project, including removal, staging, dewatering, water treatment, sediment transport, and sediment treatment, reuse, or disposal. Transport and disposal options for contaminated sediment are sometimes complex and controversial and should be investigated and discussed with stakeholders early in the project. In some cases, specialized methods of operation or equipment may be needed to minimize resuspension of sediment and transport of contaminants. Project managers should make realistic, site-specific predictions of residual contamination (i.e., contamination that remains within or adjacent to the dredged area after dredging) based on pilot studies or data from comparable sites. Where residuals are a concern, thin layer placement/backfilling, MNR, or capping may also be needed.

In addition, Chapter 6 discusses potential advantages and limitations of contaminated sediment removal by dredging and excavation. One of the principal advantages of dredging and excavation is often that, if they achieve cleanup levels for the site, they may result in the least uncertainty regarding future environmental exposure to contaminants because the contaminants are removed from the aquatic ecosystem and disposed in a controlled environment. Another potential advantage of removing contaminated sediment rather than managing it in place is that it may leave more flexibility regarding future use of the water body. Although dredging remedies at sites with bioaccumulative contaminants usually include fish consumption advisories for a period of time after sediment removal, other types of institutional controls that might be needed to protect a cap or a layer of natural sedimentation are usually not necessary. The principal limitations of sediment removal are that it is usually more complex and costly than in-situ management, and that the level of uncertainty associated with estimating residual contamination can be high at some sites. The need for transport, storage, treatment (where applicable), and disposal facilities may lead to increased impacts on communities. In some parts of the country, disposal capacity may be limited in existing municipal or hazardous waste landfills and it may be difficult to site new local disposal facilities. Another limitation may include the potential for contaminant losses during dredging through resuspension, and to a generally lesser extent, through other processes such as volatilization during excavation, transport, treatment, or disposal. Finally, similar to in-situ capping, dredging or excavation typically includes at least a temporary destruction of the aquatic community and habitat within the remediation area.

Chapter 7, Remedy Selection Considerations, discusses risk management decision making, the NCP's remedy selection framework, including considering sediment remedies and comparing net risk reduction, considering alternatives that include institutional controls, and considering a "no-action" decision. Where a remedy is necessary, the best route to overall risk reduction depends on a large number of site-specific considerations, some of which may be subject to significant uncertainty. Any decision regarding the specific choice of a remedy for contaminated sediment should be based on a careful consideration of the advantages and limitations of each available approach and a balancing of trade-offs among alternatives. This chapter includes two summary tables to help with this comparison process: one describes site characteristics and conditions especially conducive to each of the three potential remedy approaches for sediment (MNR, capping, and dredging), and the other lists examples of key differences between the three potential remedy approaches with respect to the NCP's nine remedy selection criteria. Documenting and communicating how and why remedy decisions were made are especially important at complex sites. The concept of comparing "net" risk reduction may assist in the remedy selection process by providing a framework for considering elements of alternatives which may reduce risk and elements which may allow risk to continue or temporarily increase. When considering remedies that include institutional controls, project managers should consider what entities possess the legal authority, capability and willingness to implement the control.

EPA's policy has been and continues to be that there is no presumptive remedy for any contaminated sediment site, regardless of the contaminant or level of risk. At many sites, but especially at large sites, a combination of sediment cleanup methods may be the most effective way to manage the risk. The remedy selection process for sediment sites should include a clear analysis of the uncertainties involved, including uncertainties concerning the predicted effectiveness of various alternatives and the time frames for achieving cleanup levels and, if possible, remedial action objectives. The uncertainty of factors very important to the remedy decision should be quantified, so far as this is possible. Where it is not possible to quantify uncertainty, sensitivity analysis may be helpful to determine which apparent differences between alternatives are most likely to be significant.

Chapter 8, Remedial Action and Long-Term Monitoring, provides a recommended approach to developing an effective monitoring plan at contaminated sediment sites. The chapter presents sample measures of sediment remedy effectiveness, in terms of remedy performance and risk reduction. A fully successful sediment remedy typically is one where the selected sediment chemical or biological cleanup levels have been met and maintained over time, and where all relevant risks have been reduced to acceptable levels based on the anticipated future uses of the water body and the goals and objectives stated in decision documents. The chapter also presents the key steps in designing and conducting a monitoring program at a sediment site, introduces some of the monitoring techniques available for physical, chemical, and biological measurements, and summarizes some of the factors to consider when monitoring remedies including MNR, in-situ capping, or dredging/excavation. A monitoring plan typically can be important for all types of sediment remedies, before, during and after remedial action. The development of monitoring plans should follow a systematic planning process that identifies monitoring objectives, decision criteria, endpoints, and data collection and interpretation methods. Project managers should ensure that adequate baseline data are available for comparison to monitoring data after a remedial action and that adequate background data are available, including any continuing off-site contaminant contributions. Monitoring before, during, and after sediment remediation generally will help not only to answer site-specific questions but to contribute to a better understanding of remedy performance at the national level.